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GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): Evaluating the case for New York State

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A B S T R A C T

Twenty states plus the District of Columbia now have renewable portfolio standards (RPS) in place that requires a certain percentage of energy to come from renewable sources by a specific year. With renewable energy on the verge of massive growth, much research emphasis is put on enabling the implementation of these technologies. This paper presents a novel method of site selection for wind turbine farms in New York State, based on a spatial cost–revenue optimization. The algorithm used for this is built in ESRI ArcGIS Desktop 9.3.1 software and consists of three stages. The first stage excludes sites that are infeasible for wind turbine farms, based on land use and geological constraints. The second stage identifies the best feasible sites based on the expected net present value from four major cost and revenue categories that are spatially dependent: revenue from generated electricity, costs from access roads, power lines and land clearing. The third stage assesses the ecological impacts on bird and their habitats. The proposed spatial multi-criteria methodology is then implemented in New York State and the results were compared with the locations of existing wind turbine farms. The wind farm site selection tool presented in this paper provides insights into the most feasible sites for a large geographic area based on user inputs, and can assist the planning of wind developers, utilities, ISO's and State governments in attaining renewable portfolio standards.

Contents

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1. Introduction

Wind power showed immense growth in the last couple of years. In 2009, the U.S. added 9581 MW of wind generators, which is 41% of the total added power capacity that year [1]. By adding 442 MW, New York State joined the 'Gigawatt Club' in 2009, totaling 1274 MW. According to studies by the National Renewable Energy Laboratory (NREL) the total wind resource capacity in the New York State is around 25 GW for sites with a capacity factor of 0.3 or more or 65 GW if sites with a capacity factor of 0.25 or more are taken into account [2,3].

Even though all wind power project developers have to complete an environmental impact statement (EIS), few renewable energy projects are constructed without debates. Although most people embrace the arrival of clean electricity, some speak out loud about their issues with wind power. Hence, the planning and permitting of wind turbine farms is a multi-faceted process that aims to balance the opinions of all stakeholders. The locations with the highest wind resources are not always feasible sites for wind farms. A variety of factors play a role in the site selection of wind turbine farms. They can be categorized into: economic, planning, physical and ecological factors. As all of these are spatially dependent, it seems evident that the use of geographic information systems (GIS) poses benefits for site selection. Starting in the early 2000s, papers were published that introduced buffer distances to urban areas, water bodies and historic sites in order to prevent wind turbine development in sensitive areas in the UK and Denmark [4,5]. The maps that they generated were discrete classifications of suitability. Later, these types of spatial assessments were expanded with more detailed datasets for wind resources and environmental impacts in Turkey and Spain [6,7]. Also, Ramirez-Rosado et al. [7] introduced methods to include and compare tolerances of decision makers. These analyses grew out to become what we coin in this study as full spatial multi criteria assessments (SMCA) for large geographic regions.

In September 2008, the Environmental Protection Agency (EPA) launched the 'E-Powering America's Land Initiative', a program that aims to clean and use potentially contaminated land and mine sites for renewable energy generation [8]. Characteristics and spatial information of brownfields, mines and landfills were collected and evaluated using a SMCA approach. Although some critical map layers were omitted in the analysis, e.g. distance to the electric grid and urban areas, the results were useful and helped in the planning of several projects. For each State, maps were published with sites that have renewable energy potential [9] including wind resources of class 4 or higher at sites larger than 100 acres for utility scale wind. The NYS dataset did not include any "utility wind capable" sites as no contaminated lands or mine sites in NYS are in class 4 areas. Among the success stories are a 2 MW solar photovoltaic facility in Fort Carson, CO and a 45 MW Steel Winds Project near Buffalo, NY. The EPA has estimated that the national wind technical potential for the tracked sites in this initiative is more than 17,000 MW. The practically and economically feasible portion of this is not assessed.

In the current paper, we present a tool for New York State that introduces a detailed economic optimization after infeasible sites are eliminated. In addition to the previous authors' constraints and cost considerations we added geological feasibility, avoidance of important bird areas (IBA), land clearance costs, and cost optimization between upgrading existing power substations or adding new ones.

2. Methodology and criteria evaluation

We present a site selection tool for wind turbine development in New York State that comprises three stages. Stages 1 and 2 incorporate specific criteria with constraints that can be set by the user (Figs. 1 and 2).

In the first stage, sites are excluded because of planning and/or physical constraints. Infeasible sites include: (a) Federal and Indian lands that have specific functions (like national parks, army grounds, prisons); (b) sites where wind turbines would interfere with its current land use (airports, urban areas); (c) sites where it is physically impossible or problematic to install turbines (porous grounds, slopes greater than 10%). In the second stage the remaining sites are ranked based on their net present value (NPV), taking into account spatially dependent wind resources, the cost for building feeder lines to the nearest transmission line, the cost for access roads and the cost for land clearing. The relative importance of these individual cost and revenue categories are discussed in Section 2.2. In the last stage, a map of important bird areas is intersected with the highest ranked sites to show potentially problematic sites in terms of bird mortalities so that mitigation strategies can be implemented. In order to facilitate the economic evaluation of the site (energy yield, capital costs), a nameplate capacity was determined. In the example discussed below, site selection was performed for wind turbine farms with a rated capacity of 50 MW, comprising 25 Vestas V80 2 MW turbines. The GIS software on which this tool operates is ESRI ArcGIS 9.3.1 [10].

The default values of the constraints are based on earlier papers. The SMCA is fitted with default values for the criteria that the user can alter to suit his preferences. A summary of the siting criteria and default values is shown in Table 1.Radar interference of wind turbines has led the Federal Aviation Administration (FAA), the Department of Homeland Security (DHS) and the Department of Defense (DoD) to contest proposed wind farms in the line of sight of radar. The DoD found that the best solution for this problem is "non-technical mitigation", which means blocking the installation of turbines in sensitive areas. Brenner et al. [11] propose to move to a technically based rule system for determining the severity of the interference. With quantitative metrics, a consistent evaluation can be applied to proposed wind turbine farms. Besides that, they suggest numerous mitigation procedures in the form of upgrades to either wind turbines or radar systems, which would reduce interference from wind turbines. In the SMCA presented here, radar interference was not included because of a lack of data. If radar mast coordinates become available in the future, they can be added to the tool and buffered as an additional siting constraint.

2.1. Stage 1: exclusion of infeasible sites

Several map layers are used to generate the output of the exclusion stage. All are from the National Atlas GIS database, created by the United States Geological Survey [12]. The State of interest is split up in feasible and infeasible sites, depending on the user's constraint inputs for the following map layers (Table 2):

2.1.1. Planning criteria: visual intrusion, noise and safety

Visual intrusion is a somewhat debatable issue; although some people see wind turbine farms as obliteration of nature, others welcome the clean power from wind farms and like the structures in their area. According to a survey conducted in North Carolina, 58% of the respondents ($n = 400$) did not see a problem or could not think of a problem with developing a wind industry in the State [13]. Of the people who had a problem, the majority (44%) said that visual "pollution" is their major issue with wind power. However, other studies [14,15] have shown that the attitude towards wind power of the public in areas with wind farms is more positive than in areas with no prior experience. The people there are in addition more likely to accept more wind turbines in their area. Also, the change of attitudes in an area was investigated over the period of construction. Of the people who changed their

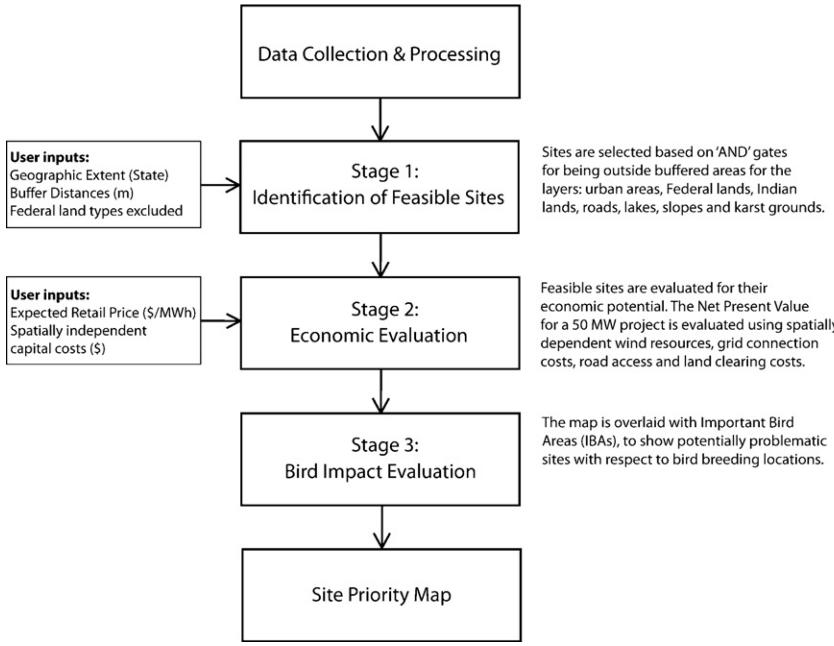

Fig. 1. Schematic of the SMCA methodology.

attitude (27% of respondents), 9 out of 10 had turned in favor of the use of wind power. The conclusion indicates that public acceptance increases with the level of information and experience [16]. Relating this to wind farm site selection, the placement of turbines in the visual periphery of urban areas and roads would benefit the public opinion on wind power and stimulate the placement of more wind turbines in the area. As a side note, this could explain the grouping of large wind farms in light populated areas of Texas and Minnesota, even though high wind resources are widespread.

Noise is a quantifiable issue and more guidelines and regulations can be found on this aspect. Typically, wind developers keep 500 m distance of single dwellings in order to keep sound levels at an appropriate level [4–6]. Since noise is the major reason for setbacks from urban areas, it is useful to look into it in more detail. Noise propagation can be described by the logarithmic relations of sound power level at the source (L_w) and sound pressure level at a location (L_p), both measured in dB. A simple relation between L_p and distance to turbines is given as:

$$L_p = L_w - 10\log_{10}(2\pi R^2) - \alpha R$$

where

$$R^2 = H^2 + X^2$$

H is the tower height and X is the observer's distance to the tower. α is the atmospheric absorption of 1000 Hz sound and corresponds to 0.005 dB/m. With the Vestas V80 sound power level of 100 dB at the hub and a tower height of 78 m, the following approximate decrease of sound pressure level over distance can be expected.

A summary of regulations for the maximum sound pressure level in provinces of Canada was published in 2007 [17]. They range anywhere between levels of 40 and 55 dB, values that are well within a distance of 500 m.

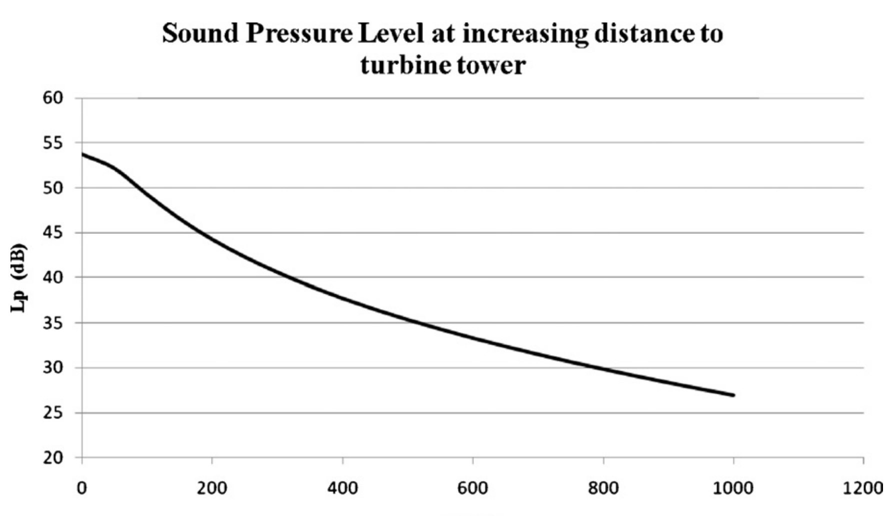

Fig. 2. Approximation of the sound pressure level as a function of distance to the turbine tower for a source L_w = 100 dB and tower height of 78 m.

Table 1
Overview of the spatially dependent criteria compiled from four wind farm site selection studies. Denoted distances like '500–1500 m' are fuzzy sets (in the last two columns), thus the tolerance goes from 0 to 1 between 500 and 1500 m from the object.

Study		Baban and Parry [4]	Ramirez-Rosado et al. [7]	Hansen [5]	Aydin et al. [6]
Area of study		Lancashire, United Kingdom	La Rioja, Spain	Northern Jutland, Denmark	Southwest Turkey
Economic	Wind resources	x > 5 m/s and > 500 m from forest	x (WASP)	x (250–650 W/m^2)	x (200–400 W/m^2)
	Electric line cost	x < 10 km	x		
	Electric integration cost				
	Land cost		x		
	Access Road cost	x < 10 km	x		
Planning	Visual impact	x (500 m single dwellings, 2000 m towns)	x (impact index fuzzy)	x (500–1500 m settlements, 150–450 m roads)	x (1000–3000 m)
	Safety distances urban areas	x (2000 m)	x	x (500–1500 m)	x (1000–3000 m)
	Noise	x (500 m)	x	x (500–1500 m)	x (400–500 m)
	Electromagnetic interference	Mentioned but omitted	x	x (1000–2500 m radio masts	Mentioned but omitted
	Parks, military, airports, prisons, etc.	x (1000 m parks)	x	x (5000–7500 m airports)	x (3000–6000 m airports)
Physical	Slope	x < 10%	x		
	Altitude		x		
	Karst (porous grounds and caves)				
Ecological	Bird habitats/routes		x		x (2500–5000 m)
	Forest proximity	only for wind resource purpose	x	x (300–800 m)	x (allowed by Turkish regulation)
	Lakes and rivers	x (400 m)		x (150–650 m streams and lakes, 1000–4000 m coast)	x (2500–5000 m around wetlands)

Although modern wind turbines rarely show safety concerns, safety distances for blade and ice throws should be maintained. Because of the rare occasion of blade throws in modern turbines, no extensive research has established a safety distance as a function of turbine height and rotor diameter. However, Larwood [18] compared a series of simulations and small scale experiments to come up with maximum blade and blade fragment ranges for different turbine heights at normal operating conditions. The maximum range is expressed in turbine heights and is calculated to be ~130 m for blade fragments of a 25 m high turbine. For the typical size of 80 m, the maximum range is about 350 m. Ice throws are better understood. Ice throw strikes in moderate icing conditions (5 icing days/year) were found to be 1 in 1,000,000/year, at a distance of 350 m [19]. For ice throws, care should be taken with roads, as ice fragments might present potential hazards to traffic. From these safety ranges it can be concluded that the 500 m range for noise pollution is sufficient to account for safety against blade and ice throws as well.

Besides the criteria mentioned above, wind energy projects are not likely to be allowed in lands serving a specific purpose like national parks, army grounds, prisons, wildlife refuges and air force bases. These sites, as well as Indian reservations, are excluded from the map.

2.1.2. *Ecological criteria*

Ecological impacts of wind turbines can be categorized in three groups: collision hazards for birds and bats, destruction of wildlife habitat and destruction of vegetation. Strategic placement of turbines outside important breeding grounds and high population areas can reduce the ecological impact. Bird and bat mortalities from wind turbine collisions were counted in several studies and summarized in 2008 [20]. Eighteen wind turbine farms with in total 1569 turbines were reportedly the cause of 0.04–10 bird mortalities per turbine per year and 0.07–64 bat mortalities per turbine per year. Although the separate studies used different bias corrections and are difficult to compare, the averages give an indication of what can be expected: 2.4 birds and 12.2 bats per turbine per year. In order to prevent disturbance of animals in their habitats, wind turbines should be placed a safe distance away from breeding grounds, specifically wetlands and wildlife refuge forests. Wetlands are also protected for their hydrologic characteristics (e.g., the collection of runoff water). In the tool described here, wetlands and buffered areas around wetlands are considered infeasible sites for these reasons. Although strict regulations do not exist on distances to lakes, the EIS must comply with federal laws and regulations that oversee the environmental impact of the proposed project. Guidelines and proposed rules for setbacks range from 150 to 5000 m. Baban et al.

Table 2
Overview of the criteria used in stage 1 of the SMCA and the types of constraints associated with them. The buffered distances show setbacks assigned to wind farm feasibility. All datasets are from the United States Geological Survey [12].

Layer	Constraint	Factor	Buffer (default)	Year of data
Urban areas	Visual intrusion, noise	Planning	1 km (towns), 2 km (cities)	1998
Federal lands	Regulations	Planning	–	2005
Indian lands	Regulations, visual intrusion	Planning	3 km	2005
Roads	Safety, visual intrusion	Planning	0.5 km	1999
Lakes	Animal habitat, hydrology	Ecological	3 km	2003
Slope	Construction accessibility	Physical	< 10% slope (no buffer)	1993
Karst (porous grounds and caves)	Foundation strength requirement	Physical	–	2005

collected guidelines from 60 local authorities in the UK by means of a survey and determined a representative distance of 400 m to water bodies. This distance was set as the default constraint in the NYS site selection tool presented here.

2.1.3. Physical constraints

Physical constraints for slopes were set at 10%, based on survey replies from four private wind developer companies [4]. Construction of turbines on slopes greater than 10% is difficult because of limited accessibility of the cranes needed to lift heavy turbine components. The slope raster dataset was derived from a GTOPO30 digital elevation model (DEM) using the 'slope' function in ArcMap. Cell size is approximately 1 km. Another important consideration is the presence of porous grounds and caves (or karst). Since the foundations of wind turbines transfer the weight of the turbines to the ground, they must withstand great forces. Poor soil conditions can raise costs for the foundation type by 100% or more [21]. Besides posing structural implications, caves are often home to endangered species of fauna and are therefore avoided. From the USGS karst dataset, a selection is made for karst that is above 100 m depth and these areas are considered infeasible. For NYS, no locations were subtracted from the map, but it is important to take into consideration.

After the model subtracts all the above discussed areas from the map (including buffered zones), the remaining sites are evaluated for their economic potential (stage 2) and reviewed on impacts on birds and their habitats (stage 3).

2.2. Stage 2: economic evaluation

Wind energy developers aim for the highest economic return of their project to satisfy the investor interests and make profits. Stage 2 of the SMCA addresses the economical value of potential wind development sites. Besides the expected rate-of-return (ROR), the investment risk is also important. Investment risks exist in both pre- and post-construction periods. Before construction there is the risk that the wind project experiences opposition from local inhabitants and environmental groups for the reasons discussed in stage 1. Besides them, independent system operators (ISO's) can pose implications for grid congestion issues and connection costs. Post-construction, the main economic risk is from lower-than-expected yield and higher O&M costs. Even though the major cost component of wind power is not spatially dependent (the wind turbines), other components like foundations, road costs and grid connection are and they vary considerably with location. An overview of capital costs, summarized by the EWEA, is given in Table 3.

Part of the grid connection and road construction costs can be considered fixed, since they include roads and power lines between turbines and they do not vary with the location of the entire wind farm. Similarly, since urban areas and karst grounds are avoided, land costs and foundation installations should not vary significantly between sites. From this table and a paper published in 2009 [25], the spatially dependent costs are estimated to be approximately 15–20% of the total costs. In the SMCA presented here, the spatially independent costs are estimated to be 79 M$ for a 50 MW wind turbine farm, based on a survey of installed project cost of $1920/kW in 2008 [26]. The spatial cost components of road construction, grid connection and land clearing were added individually as follows.

2.2.1. Grid connection

Grid connection costs are calculated in this model as a function of distance to the nearest electricity line or substation. Some GIS-based spatial planning systems have been presented and published before that completely neglected proximity to the grid and grid integration [5,6]. Baban et al. included a maximum distance to the grid (10 km) as a criterion. A more detailed assessment was done by Ramirez-Rosado et al. where a minimal cost path was found by an optimization function in the GIS. Distance to the nearest grid is important for feeder line costs, as well as power loss (the shorter, the better). For the tool presented here, a map with substations and transmission lines from the New York independent system operator (NYISO) was used. Based on Green et al. [27], it is estimated that the spatially variable grid connection costs are a function of the required building or upgrading of a substation (C_{new}, resp. C_{upgrade}) and the distance to an existing transmission line or substation (x_{w-l} resp. x_{w-s}) in km. These investigators estimated the costs for three onshore 18 km cables at 5.59 M$ for the Danish 160 MW Nysted wind farm. A single (53 MW) cable is therefore assumed to cost $100,000/km ($c_{\text{line}}$). Another source reports at least $200,000/mile (125 $/m) [28]. The cost for feeder lines varies considerably due to fluctuating commodity prices. The cost for a new substation is interpolated at 5 M$, while upgrading an existing substation (shunt reactor, bus bar protection, etc.) is estimated to cost 2 M$. This translates into two simple cost equations that are calculated for each location on the map. The cost of connecting to an existing substation is given by:

$$C_s = C_{\text{upgrade}} + (c_{\text{line}} x_{w \to s})$$

The cost of adding a substation and connecting to an existing line is given by:

$$C_l = C_{\text{new}} + (c_{\text{line}} x_{w \to l})$$

The minimum of C_s and C_l is integrated into the SMCA. Besides the cost for feeder lines that connect the wind farm to the grid, congestion of transmission lines should be taken into account. When proposing a multi-megawatt wind farm connection to the grid, power flow analysis should be undertaken in order to assess whether the downstream transmission lines are able to cope with the extra load. The results of such an analysis can be added to the model.

2.2.2. Access roads

Access roads need to be sufficiently wide (typically 15 feet) and have strong pavements so that heavy cranes and trucks carrying components can navigate to the turbine sites. Typically are built by flattening and compressing the surface of the ground and gravel is deposited to prevent slipperiness in wet weather conditions. Costs are set to $25/foot, or $82,000/km [28] to the nearest existing road.

2.2.3. Land clearing

Land clearing costs are a less significant cost factor; the cost depends on the type of vegetation present on site. For this, the National Land Cover Database was utilized [24], along with web-references for land-clearing costs. From the total acreage of the project, only 5–10% of the land is used for control buildings, access roads, turbines [29]. The rest can maintain its former use (e.g., agriculture). For the proposed 50 MW farm in the tool, approximately 12 km^2 are used [30]. The land that needs to be cleared is therefore on average about 1 km^2. An overview of the estimated costs is given in the table below. The NLCD of 2007 shows 17 different land cover types, of which 8 would require land clearing; these are listed in Table 4.

The prices are based on a few references found online [31], since no published information about land clearing costs is available.

2.2.4. Wind resource

The most important factor that plays a role in economic feasibility is the local wind resource. The Associated Weather Services (AWS) identified 66 on-shore sites with various nameplate capacities, and capacity-factors representing about 14.8 GW of wind turbine installations [32,33]. It appears that most of the 66 sites

Table 3
Breakdown of the capital cost components for a typical onshore wind farm in Europe [22].

Component	Cost range (% of total)	Spatially dependent	Source of dataset
Grid connection	2–10	Yes	[23]
Foundation	1–9	Yes	Included in stage 1
Land/clearing	1–5	Yes	[24]
Road construction	1–5	Yes	[12]
Wind turbines	68–84	No	NA
Electric installation	1–9	No	NA
Financial costs	1–5	No	NA
Consultancy	1–5	No	NA

Table 4
Land clearing costs for different types of vegetation in the USGS database.

Category	Description	Clearing costs ($/acre)	Clearing costs for 50 MW wind farm* ($)
Evergreen forest	>5 m tall evergreen	~3000	741,000
Deciduous forest	>5 m tall sheds foliage seasonally	~3000	741,000
Mixed forest	>5 m tall, both deciduous and evergreen mixed.	~3000	741,000
Shrub/scrub	<5 m tall (true shrubs, young trees)	~1000	247,000
Hay/pasture	Grasses, legumes, plants for livestock grazing	~60	15,000
Barren land	Bedrock, desert pavement, scarps, talus, slides, sand dunes, etc.	~40	10,000
Cultivated crops	Annual crops (corn, soybeans, vegetables)	~40	10,000
Herbaceous	Grassland/herbaceous > 80% of total vegetation	~40	10,000

* The clearing costs for a 50 MW project correspond to an area of 1 km^2 [31].

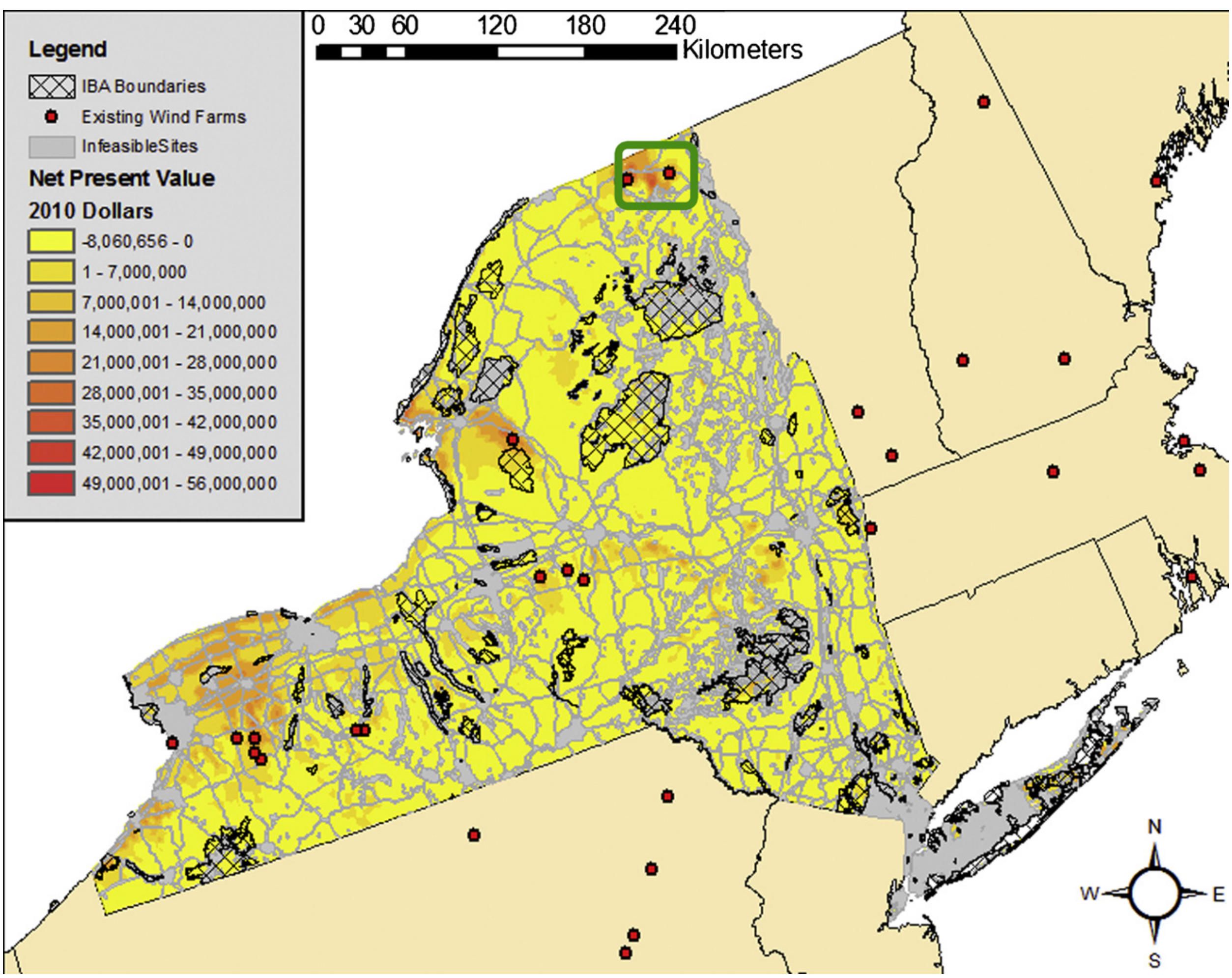

Fig. 3. Priority map showing the results of site selection modeling for New York State. None of the existing wind turbine farms were found to be located within 'infeasible sites' and important bird areas (IBAs). The green rectangle in the North of the State is the area of Fig. 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

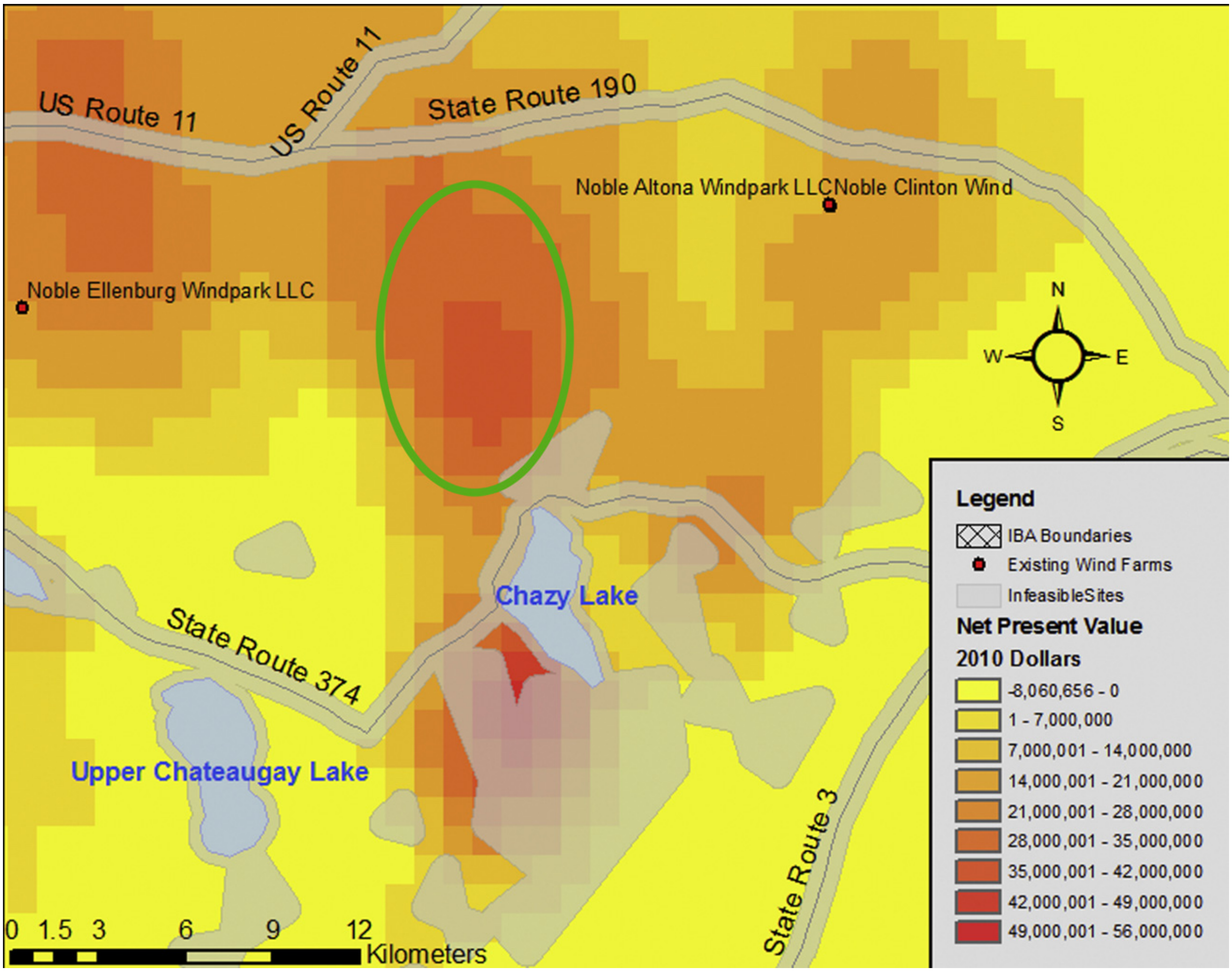

Fig. 4. Example of site selection for a high-potential wind project (green oval) in the North of NYS. The highlighted location has the second highest net present value class found by the model in NYS. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

are located at or around the locations identified as high NPV areas found by the SMCA tool presented in this paper. However, this AWS analysis did not include a detailed cost assessment and therefore sites are included that are >20 km away from the nearest high-voltage substation. In practice, sites closer to the grid with similar wind resource would be preferred. Besides the lower cost for power lines, it will have lower losses for transmission. Assessments of wind resources based on geophysical and meteorological data over large geographic areas are available from AWS Truepower. With a time series of wind speed, direction, pressure and temperature data for a selected location at a certain height [34], AWS is able to estimate the annual energy production (AEP) with an uncertainty of 10–15%. As a resource assessment for this tool, an AWS map was imported to the GIS. It shows average wind speeds at increments of 0.5 m/s at 80 m height [35]. Compared to the rest of the United States, New York State shows mediocre average wind speeds of up to ~8 m/s in some areas, which translates into wind class 4. Most of the State is class 2 and 3. The expected electricity yield of the 50 MW farm is based on a Rayleigh distribution of wind speeds and the power curve of a Vestas V80 2 MW wind turbine [36]. Array wake losses and electrical losses were assumed at 20% of AEP [37]. The estimated AEP was cross-checked with existing wind turbine farms using the EPA's eGRID database, which contains recorded electricity production numbers for 2004 and 2005. The average AEP of existing farms built between the years 2000 and 2003 corresponded to the expected yield for their locations, but a 25% error was found. This error can be explained by different sizes and brands of turbines, since the variability in AEP data of the eGRID database is substantial, even for the same wind farm in the two different years. The total revenue from electricity production is translated into the net present value by annualizing the electricity yield multiplied with the expected revenue (default: 72 $/MWh [38]). This electricity price can be changed by the user of the tool, in case a fixed price bilateral agreement is negotiated with a private party.

2.3. Stage 3: bird impact evaluation

Sites are also evaluated for potential impacts on birds. Although a thorough environmental impact analysis is required for the EIS, it is beneficial to address impacts on birds before a site is selected. One existing dataset that provides some information on critical bird habitats is the dataset for "Important Bird Areas", which was obtained from Audubon [39]. The IBA program is an international bird conservation initiative, which identifies IBAs according to standardized, scientific criteria through a collaborative effort among government agencies, conservation groups, academics, and environmental groups. So far, 136 IBAs are identified in New York, with a total area of 3.5 million acres. Besides the spatial extent of the IBAs, the dataset shows what types of birds congregate in large numbers in each IBA, including a marker for species at risk (SAR) and responsibility species assemblages (RSA). The latter is for habitats of assemblages of species whose long-term conservation is the responsibility of New York State. None of the 15 existing wind tur-

Table 5
Overview of the number of wind farms and total capacity found in each net present value class, based on the results of spatial economic evaluation.

NPV class	NPV range (M$)	# Wind farms	Total capacity (MW)
1 (Worst)	−8 to 0	1	37.5
2	0–7	2	99
3	7–14	1	40
4	14–21	1	20
5	21–28	7	661.6
6	28–35	1	30
7	35–42	1	81
8	42–49	1	322
9 (Best)	49–56	–	–

bine farms in the State happen to be located in any of these areas. Along with the feasibility and economic optimization map, the IBAs can help in finding the right location for a wind project. However, comprehensive site surveys have not been conducted for each IBA, therefore, the data provided by IBAs cannot be relied on as a definitive statement of the presence or absence of all species at a given location. Therefore, individual site assessments are still necessary.

3. Results

An overview of the results for wind farm site selection in New York State can be seen in Fig. 3. The default values discussed above were used as inputs for the SMCA. The results of stage 1–3 are respectively shown as: gray infeasible site polygons, colored (yellow to red) raster of net present value and cross-hatched IBAs.

According to the model and the listed constraints and economic assumptions, the total capacity of wind that can be installed in NYS amounts to 86 GW, based on 4 MW/km^2 of feasible sites, excluding sites with a negative NPV. AWS estimated a potential generating capacity of 65 GW wind, for sites with a capacity factor above 0.25. Our results include sites that have a lower capacity factor but are located close to an existing substation and access road and therefore have favorable economics. The results of the SMCA were compared with the locations of 15 existing wind farms (1281 MW). None are located in areas that were deemed infeasible according to our model. Regarding economic evaluation, it is found that existing wind farms are located in- or close to high NPV centers. With the net present value split up in 9 classes, it is found that the farms are located as can be seen in Table 5:

It should be noted that the areas of 7, 8 and 9 are only very small portions of the map and most of them are in mountainous areas, where steep slopes make wind turbine development complicated. According to the model, all but one (Dutch Hill Wind Power Project) creates a net profit for the developer. The analysis is based on aggregated values, since the locations of wind farms are represented by points, not polygons. The points on the map are set to a wind turbine located in the middle of the farm. A more accurate method would be to map every individual wind turbine in a farm and then sum the expected yield to find the aggregate yield for the wind farm.

Fig. 4 shows details of site selection optimization in an area in the north of New York State; the green oval shows an area of ~22 km^2 where a high NPV class was determined by our model. This demonstrates how the tool can be used for selecting high-potential sites for wind turbine projects.

4. Conclusion

Site selection for wind turbine projects is of great importance. Many acceptance issues can be prevented by early selection of the right location for a project. A GIS provides powerful calculating capacity that can assess multiple layers of large geographic areas and display the results in usable maps. The spatial multi criteria analysis tool presented in this paper showcases the use of GIS for site selection in New York State. It shows that it can successfully select feasible sites, assess their economic value and give a preliminary impact assessment on birds' habitats. Besides this, it can be used for prioritization of sites for effectively achieving renewable portfolio standard goals. It should be noted that this GIS tool does not make an individual assessment of the project site redundant, as the expected yield is an estimate, and a thorough environmental impact analysis is required for the EIS.

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